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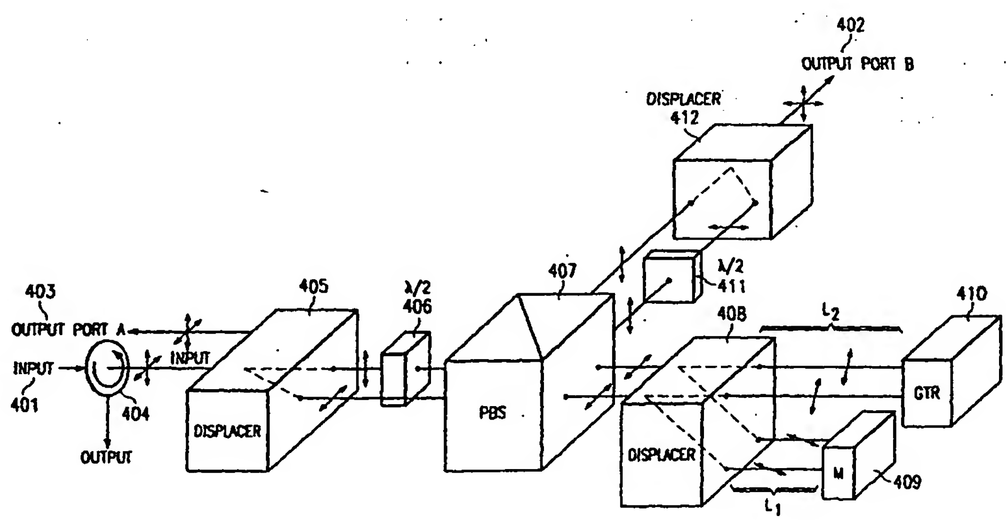

(57) Abstract: The inventive filter implements a polarization-based interferometer that uses a GT resonator. The filter includes a first displacer that receives input beam and separates the beam pass according to its polarizations. A second displacer, with an optical axis that is offset with respect to the first displacer, separates the beams, according to their polarizations, into two pairs of beams. The filter uses a GT resonator and a mirror to reflect the two different pairs of beams polarization beams. The reflective light back propagates through the second displacer, and recombines to form one pair of beams. During recombination, the combined state of the polarization of the recombined beam depends on the phase delay between the two components. The horizontal polarization component contains one set of inter-leaved wavelengths, while the vertical polarization component contains the complement set of inter-leaved wavelengths.

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OPTICAL DEVICE HAVING POLARIZATION ELEMENTS

RELATED APPLICATIONS

The present application claims the benefit of co-pending U.S. Provisional Patent Application No. 60/200,883, entitled "OPTICAL WAVELENGTH ROUTER," filed May 1, 2000, the disclosure of which is hereby incorporated herein by reference. The present application is also related to concurrently filed U.S. Patent Application [Attorney Docket No. 55872-P053US-10001288], entitled "LOW LOSS ULTRA STABLE FABRY-PEROT ETALON," the disclosure of which is hereby incorporated herein by reference.

TECHNICAL FIELD

The present application relates in general to optical communications, and in specific to using a wavelength filter in wavelength division multiplex communications.

BACKGROUND

Optical wavelength division multiplexing has gradually become the standard backbone network for fiber optic communication systems. WDM systems employ signals consisting of a number of different wavelength optical signals, known as carrier signals or channels, to transmit information over optical fibers. Each carrier signal is modulated by one or more information signals. As a result, a significant number of information signals may be transmitted over a single optical fiber using WDM technology. These optical signals are repeatedly amplified by erbium-doped fiber amplifiers (EDFA) along the network to compensate for transmission losses. The amplified signals reach the receiving end and are detected using WDM filters followed by photo receivers.

Fiber optic communications networks are typically arranged with a plurality of terminals in any of a number of topological configurations. The simplest configuration is two terminals communicating data over an optical link. This can be extended to a daisy-chain configuration in which three or more terminals are connected in series by a plurality of optical links. Ring configurations are also used, as well as other two-dimensional mesh networks. In each case, the optical link between two terminals typically includes a plurality of optical fibers for bidirectional communications, to provide redundancy in the event of a fault in one or more of the optical fibers, and for future capacity.

Despite the substantially higher fiber bandwidth utilization provided by WDM technology, a number of serious problems must be overcome, for example, multiplexing, de-multiplexing, and routing optical signals, if these systems are to become commercially viable. The addition of the wavelength domain increases the complexity for network management because processing now involves both filtering and routing. Multiplexing involves the process of combining multiple channels (each defined by its own frequency spectrum) into a single WDM signal. De-multiplexing is the opposite process in which a single WDM signal is decomposed into individual channels or sets of channels. The individual channels are spatially separated and coupled to specific output ports. Routing differs from de-multiplexing in that a router spatially separates the input optical channels to output ports and permutes these channels according to control signals to create a desired coupling between an input channel and an output port.

Note that each carrier has the potential to carry gigabits of information per second. Current technology allows for about forty channels or optical carriers, each of a slightly different wavelength, to travel on a single-mode fiber using a single WDM signal. The operating bands are limited by the EDFA amplifier (C) band, thus the increase in the number of channels has been accomplished by shrinking the spacing between the channels, and by adding new bands. The current standard is 50 and100 GHz between optical channels, whereas older standards were 200 and 400 GHz spacings. Another characteristic of the WDM signal is the modulation rate. As the modulation rate is increased, more data can be carried. Current technology allows for a modulation rate of 10 Gigabits per second (Gbs). This has been recently increased from 2.5 Gbs. The 10 Gbs standard is SONET OC-192, wherein SONET is synchronized optical network and OC is optical carrier. The increase in the modulation rate translates into a wider signal in the spatial domain. Consequently, the wider signal and smaller spacing means that the signals are very close together (in the spatial domain), and thus are very hard to separate. As a result, crosstalk may occur from adjacent signals.

One prior art separation method is to use a Fourier based filter to pass a particular wavelength from the input signal and block the other wavelengths on the signal. Such a filter 100 is depicted in FIGURE 1A, wherein the filter 100 receives a WDM signal 101, which comprises λ1, λ2, and λ3. The filter 100 blocks λ1 and λ3, and passes λ2 as output signal 102. The filter 101 has the transmission characteristics 103 shown in FIGURE 1B. Note that this filter 101 has a low peak to valley ratio, i.e. the peak is not much higher than the floor. Thus, filter will have high cross-talk from adjacent channels. To provide a higher signal-to-noise ratio, several identical filters 100a, 100b, 100c, can be cascaded together as shown in FIGURE 1C. These filters also receive WDM signal 101, which comprises λ1, λ2, and λ3, and blocks λ1 and λ3, while passing λ2 as output signal 102. The cascaded filters 100a, 100b, 100c have the transmission characteristics 104 shown in FIGURE 1D. Note that the cascaded filters have a higher peak-to-valley ratio than the single filter of FIGURE 1A. Thus, the cascaded filters will have higher (better) signal-to-noise ratio. However, also note that this filter has a narrower width than the filter of FIGURE 1A, thus this arrangement has better isolation but at a cost of having a narrower pass band.

Another prior art separation method is to use a Fourier based, Mach-Zehnder filter to divide the input signal into two periodic, inter-digitated sub-signals, each carrying an odd or even set of alternating wavelength signals, see Cohen et al. United States Patent number 5,680,490, which is hereby incorporated by reference. As shown in FIGURE 2A, the WDM input signal 201 comprises a plurality of wavelengths, $\lambda 1$, $\lambda 2$, $\lambda 3$, and $\lambda 4$. The filter 200 separates the input signal 201 into two sub-signals, which have complementary, inter-digitated wavelengths, one signal 202a with the odd wavelengths, $\lambda 1$ and $\lambda 3$, and the other signal 202b with the even wavelengths $\lambda 2$ and $\lambda 4$. Note that even and odd do not literally mean even and odd numbers, but rather indicate that alternating wavelengths in the input stream are separated into two streams. This usage will become apparent in the discussion of FIGURE 2C. The filter 200 has the transmission characteristics 206 and 207, for outputs 202a and 202b respectively, as shown in FIGURE 2B. Several filters can be cascaded to isolate single wavelengths, as shown in FIGURE 2C. The second stage filters 203a, 203b have pass bands that are twice the size of first stage filter 200, as shown in FIGURE 2D, which depicts characteristic 205 which corresponds to signal 202a, and characteristic 207 which corresponds to signal 204a of filter 203a. The other characteristics of filters 203a and 203b are not shown for the sake of simplicity. Note that the transmission profiles shown in FIGURE 2 are idealized, as the peaks are actually not flat, which reduces both the transmission band and the stop band of the filters.

A further type of filter incorporates a Michelson interferometer. FIGURE 3A depicts a standard arrangement for a Michelson interferometer 300. An interferometer 300 is a device that can be used to measure lengths or changes in length with great accuracy by means of interference fringes, and operates as follows.

Light leaves particular point of a source 301 and falls on half-silvered mirror (or "beam splitter") 302. This mirror 302 has a silver coating just thick enough to transmit half the incident light and to reflect half of the light, in other words, at mirror 302, the light divides into two portions. One portion proceeds by transmission toward mirror 303, and the other portion proceeds by reflection toward mirror 304. The waves are reflected at each of these mirrors and are sent back along their directions of incidence, each wave eventually leaving the interferometer via output 305. Since the light portions are coherent, being

derived from the same point on the source 301, they will interfere, either constructively or destructively.

If the mirrors 303 and 304 are exactly perpendicular to each other, the effect is that of light from source 301 falling on a uniformly thick slab of air, between glass, whose thickness is equal to d2 - d1. Interference fringes appear, caused by small changes in the angle of incidence of the light from different points on the source 301 as it strikes the equivalent air film. For thick films a path difference of one wavelength can be brought about by a very small change in the angle of incidence.

If mirror 304 is moved backward or forward, the effect is to change the thickness of the equivalent air film. Suppose that the center of the (circular) fringe pattern appears bright and that mirror 304 is moved just enough to cause the first bright circular fringe to move to the center of the pattern. The path of the light beam striking mirror 304 has been changed by one wavelength. This means (because the light passes twice through the equivalent air film) that the mirror must have moved one-half a wavelength. By such techniques the lengths of objects can be expressed in terms of the wavelength of light.

FIGURE 3B depicts a bandpass filter 300' using a Michelson interferometer. The band filter 300' operates similarly to the interferometer of FIGURE 3A, except that mirror 303 has been replaced with GT (Gires-Tournois) mirror 306. The GT mirror 306 is a resonator cavity comprising mirror 307, and moveable mirror 308. Mirror 308 is controlled by controller 309 to vary the distance d between the mirrors 307 and 308. This filter 300' is explained further in Dingle et al., "Properties of a Novel Noncascaded Type, Easy-to-Design, Ripple-Free Optical Bandpass Filter", Journal of Lightwave Technology, volume 17, number 8, August 1999, which is incorporated herein by reference.

The GT mirror 306 introduces a non-linear phase into the transmission function which widens both the transmission band and the stop band, in other words, forming a more square-wave like transmission function. The light remains trapped within the cavity d, reflecting back and forth between the two mirrors 307, 308. Mirror 307 is a partially reflecting mirror, which allows a portion of the incident light from mirror 306 to pass through and continue to mirror 302. The amount of light passing through is a factor of the reflectivity of the mirror 307. The reflectivity also determines how long a portion of light

entering the cavity will remain in the cavity, i.e. the cavity introduces a time delay called group delay. For example, if mirror 307 has a reflectance of 50%, then after five reflections in the cavity 3.125% of the light will remain in the cavity, with 96.875% of the light having left the cavity. The phase of any one portion of light leaving the cavity depends on the distance d and the number of reflections in the cavity. This phase affects the interference of the light on the B1 and B2 arms of the interferometer, which in turn changes the transmission pattern of the filter 300'. With a low reflectance of mirror 308, the non-linear effects are reduced such the filter 300' acts like interferometer 300, and produces a sine-squared transmission function. With a reflectance of .34, a relatively flat topped transmission function is produced. With a high reflectance a rippled top transmission function results.

However, Michelson interferometers are difficult to properly construct. Mirrors 304 and 306 of FIGURE 3B, as well as mirrors 303 and 304 of FIGURE 3A, must be precisely perpendicular to each other, at all points of the mirror. Similarly, mirror 302 must precisely aligned at a 45 degree angle with respect to mirrors 303, 304 or 304, 306. Any misalignment of any of the mirrors causes the filter to function improperly, as the alignment is critical for the interference to occur. Interferometers are particularly sensitive to alignment changes from vibrations and temperature changes.

Therefore, there is a need in the art for a WDM filter that has good transmission characteristics while being easy to construct and maintain.

SUMMARY OF THE INVENTION

These and other objects, features and technical advantages are achieved by a system and method which implements a GT resonator using a polarization-based interferometer. The input beam is provided to a displacer which separates the beam pass according to its polarizations. A second displacer, with an optical axis that is offset with respect to the first displacer, separates the beams according to their polarizations into two pairs of beams. The GT resonator and a mirror are placed at appropriate places to reflect the two different pairs of beams polarization beams. The reflective light back propagates through the second displacer, and recombines to form one pair of beams. During recombination, the beams interfere with each other such that a wavelength dependence on the polarizations of the beams is established. The horizontal polarization component contains one set of inter-leaved wavelengths, while the vertical polarization component contains the complement set of inter-leaved wavelengths. During recombination, the combined state of the polarization of the recombined beam depends on the phase delay between the two components. The phase delay, which is wavelength dependent, is introduced by the differences between the legs of the GT resonator and mirror, and the differences between the propagation speed in second displacer. The characteristics of the inventive interferometer are preselected to form a phase delay that produces the inter-leaved output. Thus, the interference is sensitive to the relative phase difference of the two different polarization state beams in the crystal. Note that the propagation in the pair are common mode and so the system is very insensitive to turbulence. The interferometer can also be tuned by turning the displacer with an axis that is perpendicular to the optical planes.

Therefore it is a technical advantage of the present invention to have a stable interferometer. Because the interferometer is based on polarization, the two beams that interfere are substantially spatially overlapped, thus problems such as air turbulence or vibration, are common mode. Therefore, it does not significantly impact on the phase difference between the two beams. This make the interferometer very stable.

It is another technical advantage of the present invention to be able to tune the interferometer, by changing the phase difference between the two beams by rotating the angle of the displacer around on its axis, for example, the vertical axis. Thus, the crystal

can be tuned and then fixed, e.g. glued, into position. Note that spacial shifts do not cause any interferometer drift.

It is a further technical advantage of the present invention to allow the inventive interferometer to be constructed from a combination of different crystals. Therefore, by properly choosing the combination of crystals, the different materials can cause the canceled of selected effects, for example, by selecting materials that have opposite signs of temperature coefficients, interferometer drift with temperature can be compensated. This makes it possible to construct a wavelength router with a wide operating temperature range.

The foregoing has outlined rather broadly the features and technical advantages of the present invention in order that the detailed description of the invention that follows may be better understood. Additional features and advantages of the invention will be described hereinafter which form the subject of the claims of the invention. It should be appreciated by those skilled in the art that the conception and specific embodiment disclosed may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes of the present invention. It should also be realized by those skilled in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims.

BRIEF DESCRIPTION OF THE DRAWING

For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawing, in which:

FIGURES 1A-1D depict prior art filters that isolate a single wavelength from an input signal;

FIGURES 2A-2D depict prior art filters that separate multiple wavelength input signals into odd/even sub-signals;

FIGURES 3A and 3B depicts arrangements using Michelson interferometers;

FIGURE 4 depicts a schematic diagram of a preferred embodiment for the inventive wavelength filter; and

FIGURE 5 depicts an alternative embodiment for the invention of FIGURE 4.

DETAILED DESCRIPTION

A WDM signal consists of multiple channels with each channel having its own range of wavelengths or frequencies. As used herein, the terms "channel" or "spectral band" refer to a particular range of frequencies or wavelengths that define a unique information signal. Each channel is usually evenly spaced from adjacent channels, although this is not necessary. For example, the wavelength filter shown in FIGURE 4 can be configured to separate channels based on a 50 GHz spacing between adjacent channels. Uneven spacing may result in some complexity in design, but, as will be seen, the present invention can be adapted to such a channel system. This flexibility is important in that the channel placement is driven largely by the technical capabilities of transmitters (i.e., laser diodes) and detectors and so flexibility is of significant importance.

FIGURE 4 is a detailed schematic diagram of the preferred embodiment of a wavelength filter 400. Filter 400 is a three port device, with one input port 401 and two output ports 402, 403. Note that the output port 403 is connected to the input port 401. Thus, on that fiber, input light flows in one direction, and output light flows in the opposite direction. Thus, a light separator to physically separate the light paths of the input and output lights. This separator could be either integrated within the filter or external from the filter. As shown in FIGURE 4, a circulator 404 is used external to the filter as the input/output light separator, however other types of separators could be used. For example, a non-reciprocal element, such as a Faraday Rotator can be used internally to physically separate the back propagating light from the input light. Also note that the circulator could be replaced with an isolator, this would effectively change filter 400 into a two port device, with one input port and one output port. The isolator would block or filter the light signal being sent down the input port.

The input light signal 401 entering the filter 400 is a WDM signal comprising both horizontal and vertical polarization components. Horizontal polarization, or p polarization, may be depicted as "p", "|", or a horizontal double-headed line. Vertical polarization, or s polarization, may be depicted as "s", "•", or a vertical double-headed line. Mixed polarizations may be depicted as "s/p", "p/s", "†", or both horizontal and vertical double-

headed lines. The input light 401 passes through circulator 404 and is incident on first beam displacer 405.

The beam displacer 405 is also known as a birefringent element, which spatially separates horizontal and vertically polarized components of the input signal. The first beam displacer comprises a material that allows the vertically polarized portion of the input signal to pass through without changing course because they are ordinary waves in the birefringent element 102. In contrast, horizontally-polarized waves are redirected at an angle because of the birefringent walk-off effect. The angle of redirection is a well-known function of the particular materials chosen. Examples of materials suitable for construction for all of the birefringent elements of the filter include calcite, rutile, lithium niobate, YVO4-based crystals, quartz, and other crystalline materials, and the like.

At least one of the beam components emerging from the first displacer 405 is rotated such that both components have the same polarization, i.e. both vertical or both horizontal. As shown in FIGURE 4, the vertical component is rotated into a horizontal polarization by half-wave plate 406. Note that if the horizontal component is rotated instead, then the output characteristics would be reversed. Further note that two polarization rotators could be used to selectively rotate the polarization states of both components, such that the output characteristics could be controllably switched. The beam components are then incident onto polarization beamsplitter 407.

The beamsplitter 407 operates to pass p light (horizontal or "|") through the beamsplitting surfaces, and deflects s light (vertical or "•"). Since both beams have horizontal polarization, both beams pass through the beamsplitter 407 and are incident on the second beam displacer 408. Note that the beamsplitter 407 could be replaced with another beam displacer, thus the output port B 402 would then be parallel, but spatially separated from the output port A 403.

The second beam displacer 408 is similar to the first beam displacer 405, except the second beam displacer 408 has its optical axis tilted with respect to the optical axis of the first beam displacer 405. The tilt is approximately 45 degrees. With a 45 degree tilt, then both input beams have horizontal and vertical components with respect to the optical axis of the second beam displacer 408. The directional beam displacement in the second beam

displacer is different from that of the first beam displacer, such that the displacement of 408 is about 45 degree from the displacement of 405. The second beam displacer 408 produces two outputs for each of the input beams, for a total of four outputs. The tilted vertical beams are incident onto GTR mirror 410. The tilted horizontal beams are incident onto mirror 409.

The mirror 409 comprises a surface having a reflectance of substantially 100%. Thus, the beams of light incident onto mirror 409 are reflected back to the second beam displacer 408.

The GTR mirror or resonator 410 is comprised of mirror M1 307 and mirror M2 308, which are separated from each other by distance d, as shown in FIGURE 3B. Mirror 307 has a reflectance of approximately 16% and mirror 308 has a reflectance of substantially 100%. Controller 309 varies the distance d. Alternatively, d can be fixed to a specific distance. Note that the distances L1, L2, and d are not physical distances but rather effective distances which includes the birefringent refractivity of the medium through which the light is passing. Thus an alternative from of control would be to place a variable refractive index mechanisms in the path of d, e.g. gradient glass, and an electro-optic modulator. Thus, the effective distance d could be independently controlled by varying the refractive index of the medium material over at least a portion of the distance d. The light exiting the cavity 410 is inputted back to the second displacer 408.

The relationships of L1, L2 and d, as well as the reflectively of mirror M1 307 determines the characteristics of the filter 400. The reflectivity of mirror M1 will control the profile of the transmission function of the filter 400. If the reflectivity of mirror M1 is low, meaning that most of the light reflecting off of mirror M2 passes through mirror M1, then the filter 400 will act as a Michelson interferometer. A reflectivity of about 16% (amplitude reflectance of .4) results in a wide, flat-topped or square shaped transmission function, which is the preferred embodiment. As the reflectivity is increased, ripple patterns will begin to appear in the top of the transmission function. Thus, the reflectance of the mirror, M1 307 controls the shape of the transmission characteristics of the filter.

The lengths of L1, L2, and d determine the pass band width, and the spacing between the peaks of the pass bands. Setting d equal to 2(L1-L2) results in inter-digitated

or inter-leaved transmission passbands similar to those shown in FIGURE 2B. The period of each pass band is equal to c, the speed of light, divided by 2d. The spacing between each of the pass bands is equal to the thickness of the passbands. Controller 309 can be used to change the length of d to change the size and spacings of the passbands.

The light returning from the two mirrors 409 and 410 passes through the displacer 408. The polarization state of the light passing through 408 is wavelength dependent due to the birefringence of the displacer 408. The horizontal polarization component contains one set of inter-leaved wavelengths, while the vertical polarization component contains the complement set of inter-leaved wavelengths. Note that any particular wavelength of input light is separated into two beams by displacer 408. These two beams are then recombined by the displacer 408 after traveling L1, L2 and reflecting off of mirror 409 and GTR 410, respectively. The combined state of the polarization of the recombined beam depends on the phase delay between the two components. The phase delay is introduced by the differences between L1 and L2, differences between mirror 409 and GTR 410, and the propagation speed in displacer 408. The phase delay is wavelength dependent. L1, L2, GTR 410, and the material of the displacer 408 are preselected to form a phase delay that produces the inter-leaved output. Examples of materials suitable for construction for the birefringent element 408 include calcite, rutile, lithium niobate, YVO4-based crystals, quartz, and other crystalline materials, and the like. Example values could be 4 = 5mm, L2 = 3.5mm and d = 3mm for a 50GHz inter-leaver. Note that these values are approximate values and are by way of example only as other values could be used.

The horizontally polarized light passes through the beamsplitter 407. One beam has its polarization rotated to the vertical polarization via plate 406. The first displacer 405 then recombines the light as first output light 403. This output contains, for example all of the odd channels ($\lambda 1$, $\lambda 3$, $\lambda 5$, $\lambda 7$...) of the input optical spectrum.

The vertically polarized light is deflected by the beamsplitter 407. One beam has its polarization rotated to the horizontal polarization via half wave plate 411. This plate is similar to plate 406. A third displacer 412 then recombines the light as second output light 402. The third displacer 412 is similar to the first displacer 405. This output contains, for example all of the even channels ($\lambda 2$, $\lambda 4$, $\lambda 6$, $\lambda 8$...) of the input optical spectrum.

The light output on each of the outputs would be an inter-digitated or inter-leaved wavelengths, as shown in FIGURE 2B. The cross-talk, or the distance between the tops of the transmission peaks and the valleys between the transmission peaks, is about -30 dB. Cascading several filters together, with each filter having substantially identical characteristics with the other filters, will increase the isolation. Note that the two output ports represent complimentary spectrums of the signal. In other words, port A is the odd wavelength spectrum, and port B is the even wavelength spectrum. Thus, the inventive filter has separated the light spectrum of the input signal into two interdigitated signals. This inventive filter can be cascaded with similar filters or other types of filters to form single channel output signals.

Another embodiment of the present invention is to form the beam displacer 408 from two different materials. One material would have a positive signed temperature change coefficient, while the other material would have a negative signed temperature change coefficient. This would compensate any interferometer drift caused by a change in temperature. Such an embodiment is effective over a wide operating range, e.g. from 0° to 100°C. An example is the combination of YVO_4 and $PbMnO_4$.

The two materials may be arranged to form a single device, or they may be separated, i.e. 408A and 408B, as shown in FIGURE 5. The operation of the dual device as shown in FIGURE 5 is similar to that of FIGURE 4, except that path length differences from temperature effects are canceled. Note that path length is ΔnL, where Δn is the difference in the index of the two polarization states in the material and L is length along the optical axis. Thus, total path length is Δn(1)L(A) + Δn(2)L(B). Δn(1), L(A), Δn(2), and L(B) are chosen to cancel the temperature effects.

Another embodiment of the present invention is to have the systems of FIGURES 4 and 5 be monolithic. Air gaps between the devices, e.g. PBS 407 and displacer 408, are eliminated. This would make the system more stable and smaller in size, but requires additional manufacturing costs.

Another embodiment uses co-propagating geometry. By replacing the beam displacer 408 by a waveplate, the beam that propagates inside will not separate spatially. But in the polarization sense, there will be two beams with different amounts of retardation.

This device is implemented by providing a special coating on the back side of the beam displacer, such that it is polarization sensitive. For a first polarization, this coating reflects 100%. For the second polarization it reflects 20% for example. Therefore, part of the second polarization propagates further into another mirror, which is coated 100% reflection. So, the partially reflecting mirror and the 100% reflecting mirror forms the GTR resonator for second polarization beam. Whereas the first polarization is reflected completely by the first mirror.

This polarization sensitive mirror can be made in a variety of ways. It can be made by depositing a fine structured, a so-called nano-structured coating on the surface. Because of the particular spatial structure, there is a difference in reflectance for the two different polarizations. Another mechanism is to directly deposit materials that have an inherent birefringence onto the surface. Therefore, it will also have the polarization determined reflectivity.

The GTR 410 in this system can be implemented two different ways. It can be made from a solid etalon which is basically a solid block of optical material polished at both surfaces and one side coated with a partial reflecting mirror, and the other side coated with a 100% reflecting mirror. Another possibility is to use an air gapped resonator formed by a pair of mirrors such as the described in the related co-pending U.S. Provisional Patent Application Serial Number [Attorney Docket No. 55872-P053US-10001288], entitled "LOW LOSS ULTRA STABLE FABRY-PEROT ETALON," filed May 1, 2000, which is hereby incorporated herein by reference. Since the solid etalon used in as the GTR would have a large temperature drift because usually optical solids have the large coefficient index change with temperature, the preferred implementation for the GT resonator in this system is air gapped Fabry-Perot etalon. Such an air gapped etalon has a small temperature drift and can be tuned by either the thin tuning plate or by air pressure. This eliminates the dependence on material index change with temperature, and therefore makes the resonator extremely stable with temperature. Also, this allows for fine tuning of the central wavelengths of the filter wave form to exactly match the ITV grid.

Although the present invention and its advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein

without departing from the spirit and scope of the invention as defined by the appended claims. Moreover, the scope of the present application is not intended to be limited to the particular embodiments of the process, machine, manufacture, composition of matter, means, methods and steps described in the specification. As one of ordinary skill in the art will readily appreciate from the disclosure of the present invention, processes, machines, manufacture, compositions of matter, means methods, or steps, presently existing or later to be developed that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein may be utilized according to the present invention. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps.

WHAT IS CLAIMED:

1. An optical device that separates an input signal into a first output signal and a second output signal, the device comprising:

a first separator that separates the input signal into a first beam and a second beam;

a second separator that separates the first beam into a third beam and a fourth beam, and separates the second beam into a fifth beam and a sixth beam;

a mirror that reflects the third and fifth beams back to the second separator;

a resonator that reflects the fourth and sixth beams back to the second separator, wherein the reflected fourth and sixth beams include non-linear phase, and the second separator combines the reflected third beam and the reflected fourth beam into a seventh beam and combines the reflected fifth beam and the reflected sixth beam into an eighth beam;

a third separator that separates the seventh beam into a ninth beam and a tenth beam, and separates the eighth beam into an eleventh beam and a twelfth beam;

a fourth separator that combines the ninth beam and the eleventh beam to form the first output signal; and

a fifth separator that combines the tenth beam and the twelfth beam to form the second output signal.

2. The optical device of claim 1 wherein:

the fifth separator is the first separator.

3. The optical device of claim 1 wherein:

the first output signal has a first spectral band and the second output signal has a second spectral band, and the first and second spectral bands are substantially complementary.

4. The optical device of claim 1 wherein:

the input signal includes a plurality of wavelengths that are associated with arbitrary numbers from 1 to N.

5. The optical device of claim 4 wherein:

the first spectral band comprises the odd numbered wavelengths and the second spectral band comprises the even numbered wavelengths.

6. The optical device of claim 1 wherein:

the first separator includes a first birefringent element; and

the second separator includes a second birefringent element.

7. The optical device of claim 6 wherein:

the first birefringent element has an optical axis; and

the second birefringent element has an optical axis that is oriented at an acute angle with respect to the optical axis of the first birefringent element.

8. The optical device of claim 7 wherein:

the acute angle is approximately 45 degrees.

9. The optical device of claim 6 wherein each of the first and second birefringent elements comprise a birefringent material selected from the group consisting of:

calcite, rutile, YVO4, LiNbO3, and quartz.

10. The optical device of claim 1 wherein:

the third separator includes a third birefringent element.

11. The optical device of claim 10 wherein the third birefringent element comprise a birefringent material selected from the group consisting of:

calcite, rutile, YVO4, LiNbO3, and quartz.

12. The optical device of claim 1 wherein:

the fourth separator includes a fourth birefringent element; and

the fifth separator includes a fifth birefringent element.

13. The optical device of claim 12 wherein each of the fourth, and fifth birefringent elements comprise a birefringent material selected from the group consisting of:

calcite, rutile, YVO4, LiNbO3, and quartz.

14. The optical device of claim 1 wherein:

the second birefringent element is comprised of two different materials, such that the two materials compensate for drift caused by a change in temperature of the device.

15. The optical device of claim 14 wherein the two materials are YVO4 and PbMnO4.

16. The optical device of claim 1 wherein:

the third separator is a polarization beamsplitter.

17. The optical device of claim 1 further comprising:

a first half-wave plate that rotates one of the first beam and the second beam prior to operation of the second separator; and

a second half-wave plate that rotates one of the ninth beam and the eleventh beam prior to operation of the fourth separator.

18. The optical device of claim 1 wherein:

the mirror has a reflectance of substantially 100%.

19. The optical device of claim 1 wherein:

the resonator is a Gires-Tournois resonator which includes a first mirror having a reflectance of substantially 100% and a second mirror which has a reflectance less than the first mirror.

20. The optical device of claim 19 wherein L1 is an effective optical distance between the second separator and the mirror, L2 is an effective optical distance between the second separator and the resonator, and d is an effective distance between the first mirror and the second mirror of the resonator, and the second separator, the mirror, and the resonator are arranged such that d=2(L1-L2).

21. The optical device of claim 1 wherein the input signal and the second output signal are carried by a fiber, the device further comprising:

a circulator that is coupled to the fiber and separates the input signal and the second output signal.

22. The optical device of claim 1 wherein:

the input signal is carried by a first fiber and the second output signal is carried by a second fiber.

23. The optical device of claim 22 the device further comprising:

a non-reciprocal element that separates the input signal and the second output signal, provides the input signal to the first fiber, and provides the second output signal to the second fiber.

24. The optical device of claim 22 the device further comprising:

a Faraday rotator that separates the input signal and the second output signal, provides the input signal to the first fiber, and provides the second output signal to the second fiber.

25. An optical device that separates an input signal into a first output signal having a first spectral band and a second output signal having a second spectral band, wherein the first and second spectral bands are substantially complementary, wherein the input signal comprises a plurality of wavelengths that are associated with arbitrary numbers from 1 to N, the device comprising:

a first element that separates the input signal into a first beam and a second beam, wherein the first beam has a first polarization and the second beam has a second polarization that is orthogonal to the first polarization;

a second element that rotates the first beam to have the second polarization;

a third element that separates the rotated first beam into a third beam and a fourth beam, and separates the second beam into a fifth beam and a sixth beam, wherein the third and fifth beams have a third polarization and the fourth and sixth beams have a fourth polarization, and wherein the third polarization is orthogonal to the forth polarization;

a fourth element that reflects the third and fifth beams back to the third element;

a fifth element that reflects the fourth and sixth beams back to the third element, wherein the reflected fourth beam and the reflected sixth beam include non-linear phase, and the third element combines the reflected third beam and the reflected fourth beam into a seventh beam and combines the reflected fifth beam and the reflected sixth beam into an eighth beam;

a sixth element that separates the seventh beam into a ninth beam and a tenth beam, and separates the eighth beam into an eleventh beam and a twelfth beam, wherein the ninth and eleventh beams have the first polarization and tenth and twelfth beams have the second polarization;

a seventh element that rotates the eleventh beam to have the second polarization;

an eighth element that combines the ninth beam and the rotated eleventh beam to form the first output signal;

a ninth element that rotates the tenth beam to have the first polarization; and

a tenth element that combines the rotated tenth beam and the twelfth beam to form the second output signal.

26. The optical device of claim 25 wherein:

the ninth element is the second element, and

the tenth element is the first element.

27. The optical device of claim 25 wherein:

the first output signal has a first spectral band and the second output signal has a second spectral band, and the first and second spectral bands are substantially complementary.

28. The optical device of claim 25 wherein:

the input signal includes a plurality of wavelengths that are associated with arbitrary numbers from 1 to N.

29. The optical device of claim 28 wherein:

the first spectral band comprises the odd numbered wavelengths and the second spectral band comprises the even numbered wavelengths.

30. The optical device of claim 25 wherein:

the first element includes a first birefringent element; and

the third element includes a second birefringent element.

31. The optical device of claim 30 wherein:

the first birefringent element has an optical axis; and

the second birefringent element has an optical axis that is oriented at an acute angle with respect to the optical axis of the first birefringent element.

32. The optical device of claim 31 wherein:

the acute angle is approximately 45 degrees.

33. The optical device of claim 30 wherein each of the first and second birefringent elements comprise a birefringent material selected from the group consisting of:

calcite, rutile, YVO4, LiNbO3, and quartz.

34. The optical device of claim 30 wherein:

the eighth element includes a third birefringent element.

35. The optical device of claim 34 wherein the third birefringent element comprise a birefringent material selected from the group consisting of:

calcite, rutile, YVO4, LiNbO3, and quartz.

36. The optical device of claim 25 wherein:

the sixth element includes a fourth birefringent element; and

the tenth element includes a fifth birefringent element.

37. The optical device of claim 36 wherein each of the fourth and fifth birefringent elements comprise a birefringent material selected from the group consisting of:

calcite, rutile, YVO4, LiNbO3, and quartz.

38. The optical device of claim 25 wherein:

the second birefringent element is comprised of two different materials, such that the two materials compensate for drift caused by a change in temperature of the device.

39. The optical device of claim 38 wherein the two materials are YVO_4 and $PbMnO_4$.

40. The optical device of claim 25 wherein:

the sixth element is a polarization beamsplitter.

41. The optical device of claim 25 wherein:

the second element is a half-wave plate; and

the seventh element is a half-wave plate.

42. The optical device of claim 25 wherein:

the ninth element is a half-wave plate.

43. The optical device of claim 25 wherein:

the fourth element is a mirror having a reflectance of substantially 100%.

44. The optical device of claim 25 wherein:

the fifth element is a resonator.

45. The optical device of claim 44 wherein:

the resonator is a Gires-Tournois resonator which includes a first mirror having a reflectance of substantially 100% and a second mirror which has a reflectance less than the first mirror.

46. The optical device of claim 45 wherein L1 is an effective distance between the third element and the fourth element, L2 is an effective distance between the third element and the fifth element, and d is an effective distance between the first mirror and the second mirror, and the third, fourth and fifth elements are arranged such that d=2(L1-L2).

47. The optical device of claim 25 wherein the input signal and the second output signal are carried by a fiber, the device further comprising:

a circulator that is coupled to the fiber and separates the input signal and the second output signal.

48. The optical device of claim 25 wherein:

the input signal is carried by a first fiber and the second output signal is carried by a second fiber.

49. The optical device of claim 48 the device further comprising:

a non-reciprocal element that separates the input signal and the second output signal, provides the input signal to the first fiber, and provides the second output signal to the second fiber.

50. The optical device of claim 48 the device further comprising:

a Faraday rotator that separates the input signal and the second output signal, provides the input signal to the first fiber, and provides the second output signal to the second fiber.

51. An optical device that separates an input signal into a first output signal and a second output signal, the device comprising:

first means for separating the input signal into a first beam and a second beam;

second means for separating the first beam into a third beam and a fourth beam, and separates the second beam into a fifth beam and a sixth beam;

third means for reflecting the third and fifth beams back to the second means;

fourth means for reflecting the fourth and sixth beams back to the second means, wherein the reflected fourth and sixth beams include non-linear phase, and the second means combines the reflected third beam and the reflected fourth beam into a seventh beam and combines the reflected fifth beam and the reflected sixth beam into an eighth beam;

fifth means for separating the seventh beam into a ninth beam and a tenth beam, and separates the eighth beam into an eleventh beam and a twelfth beam;

sixth means for combining the ninth beam and the eleventh beam to form the first output signal; and

seventh means for combining the tenth beam and the twelfth beam to form the second output signal.

52. The optical device of claim 51 wherein:

the seventh means is the first means.

53. The optical device of claim 52 wherein:

the first output signal has a first spectral band and the second output signal has a second spectral band, and the first and second spectral bands are substantially complementary.

54. The optical device of claim 51 wherein:

the input signal includes a plurality of wavelengths that are associated with arbitrary numbers from 1 to N.

55. The optical device of claim 54 wherein:

the first spectral band comprises the odd numbered wavelengths and the second spectral band comprises the even numbered wavelengths.

56. The optical device of claim 51 wherein:

the second means includes means for compensating for drift caused by a change in temperature of the device.

57. The optical device of claim 51 wherein the input signal and the second output signal are carried by a fiber, the device further comprising:

means, that is coupled to the fiber, for separating the input signal and the second output signal.

58. The optical device of claim 51 wherein the input signal is carried by a first fiber and the second output signal is carried by a second fiber, the device further comprising:

means for separating the input signal and the second output signal, providing the input signal to the first fiber, and providing the second output signal to the second fiber.

59. An method for separating an input signal into a first output signal and a second output signal, the method comprising:

separating the input signal into a first beam and a second beam;

separating the first beam into a third beam and a fourth beam;

separating the second beam into a fifth beam and a sixth beam;

inducing non-linear phase onto the fourth and sixth beams;

combining the third beam and the induced fourth beam into a seventh beam;

combining the fifth beam and the induced sixth beam into an eighth beam;

separating the seventh beam into a ninth beam and a tenth beam;

separating the eighth beam into an eleventh beam and a twelfth beam;

combining the ninth beam and the eleventh beam to form the first output signal; and

combining the tenth beam and the twelfth beam to form the second output signal.

60. The method of claim 59 wherein:

the first output signal has a first spectral band and the second output signal has a second spectral band, and the first and second spectral bands are substantially complementary.

61. The method of claim 59 wherein:

the input signal includes a plurality of wavelengths that are associated with arbitrary numbers from 1 to N.

62. The method of claim 61 wherein:

the first spectral band comprises the odd numbered wavelengths and the second spectral band comprises the even numbered wavelengths.

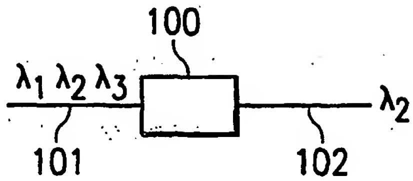


FIG. 1A

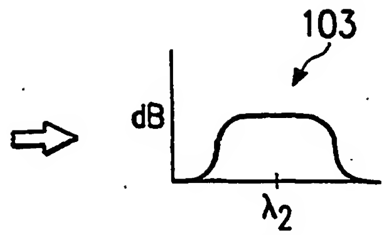


FIG. 1B

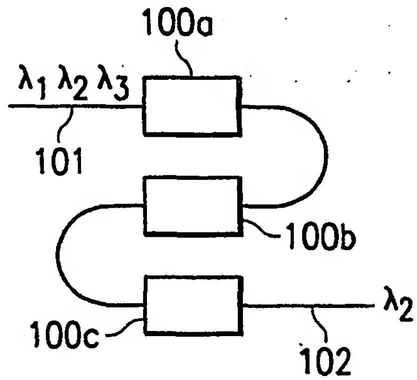


FIG. 1C

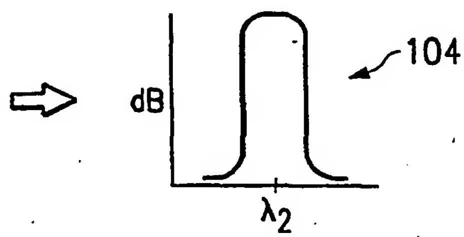


FIG. 1D

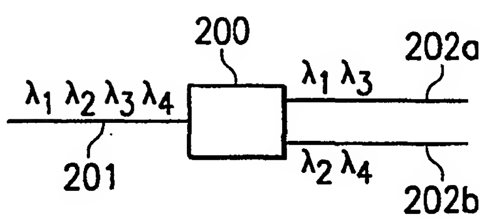


FIG. 2A

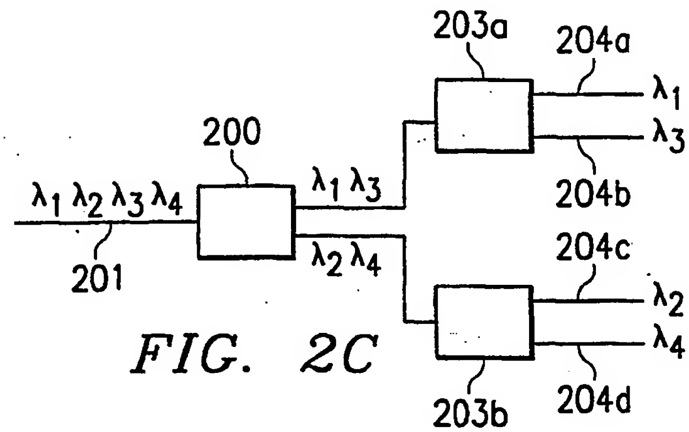


FIG. 2C

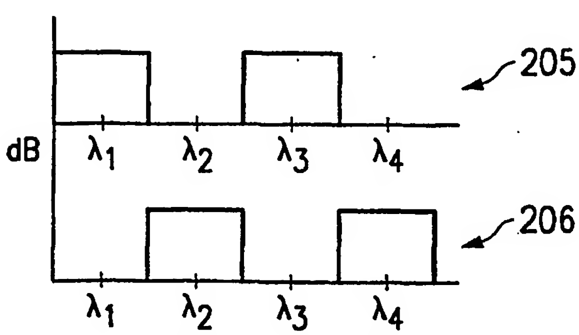


FIG. 2B

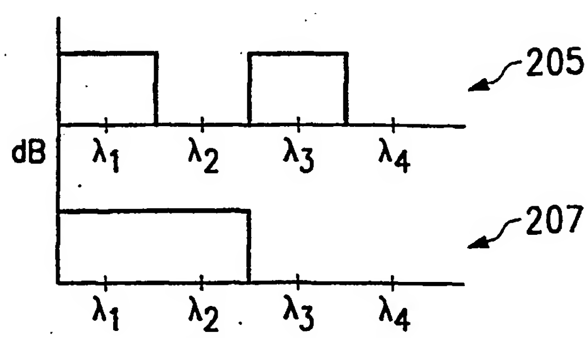


FIG. 2D

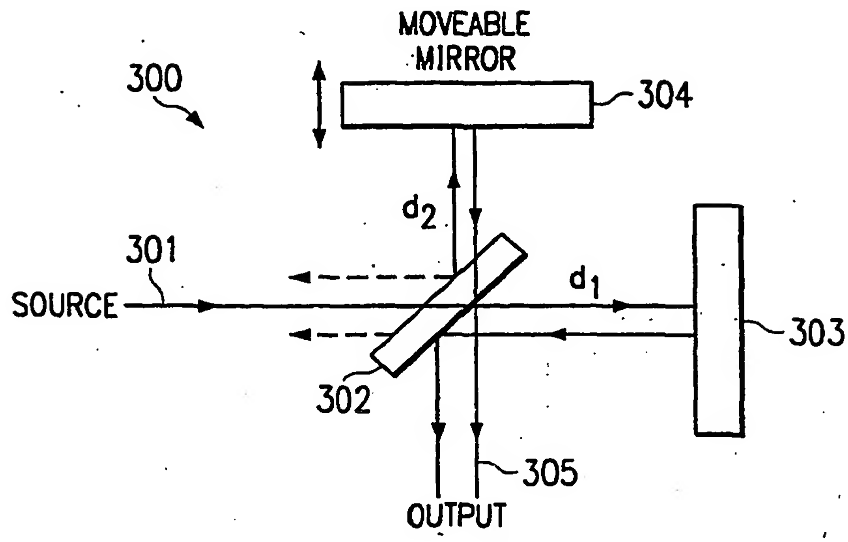


FIG. 3A

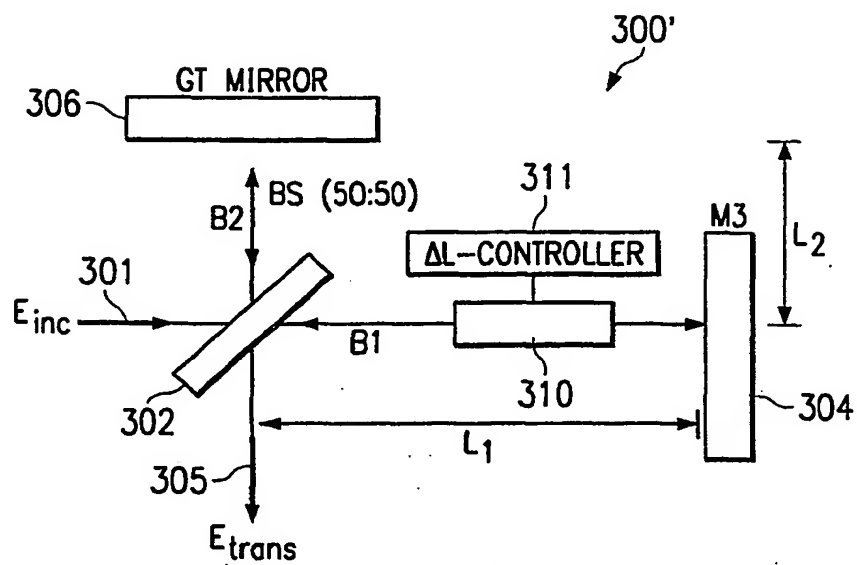


FIG. 3B

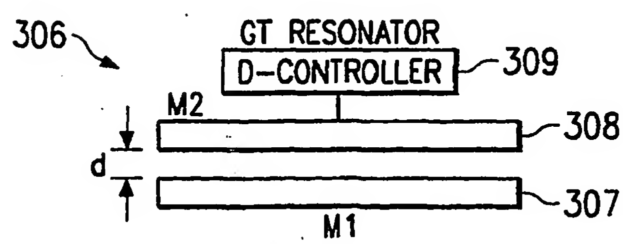
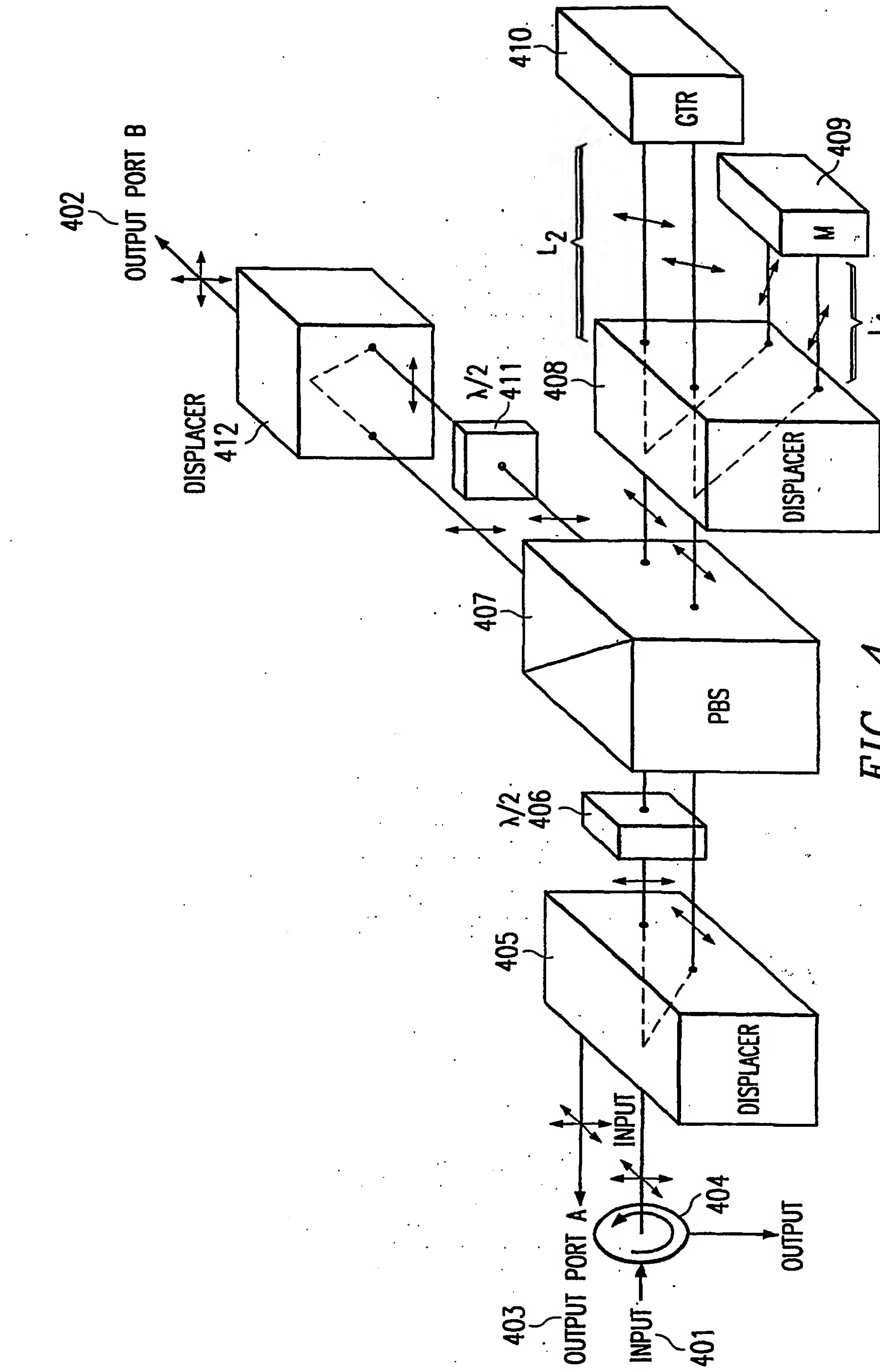


FIG. 3C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411
410
GTR
409
M
L_2
L_1
408
DISPLACER
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PBS
λ/2
406
405
DISPLACER
INPUT
403
OUTPUT PORT A
404
INPUT
401
OUTPUT

FIG. 4

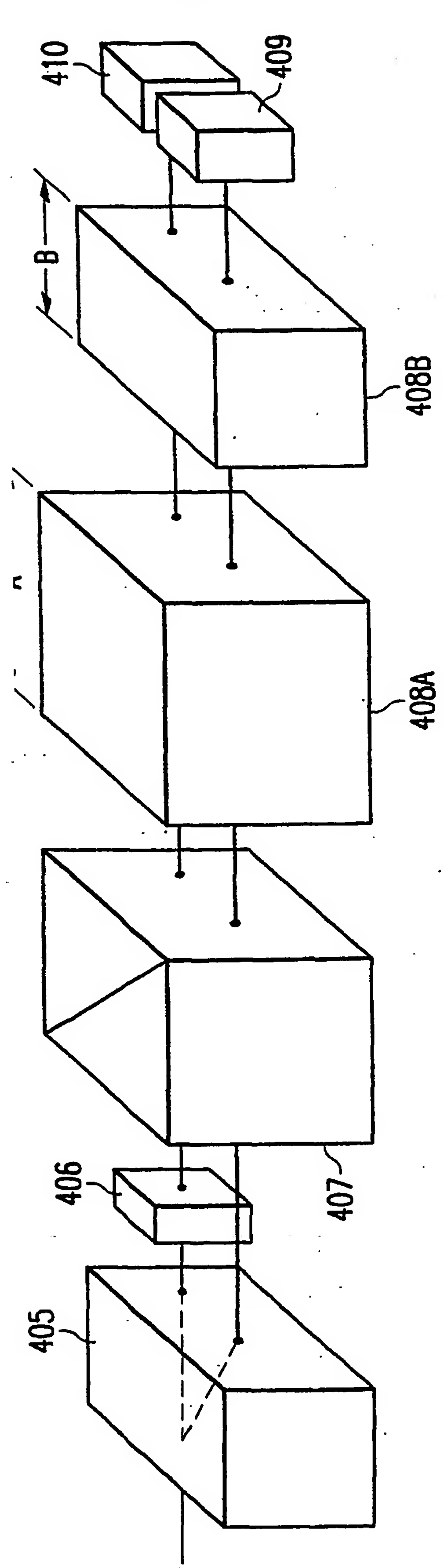

FIG. 5